Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

1g84c
op.4

The Use of AROMATIC SOLVENTS for Control of Submersed Aquatic Weeds in Irrigation Channels

LIBRARY
CURRENT SERIAL RECORD
NOV 25 1955
U. S. DEPARTMENT OF AGRICULTURE

Circular No. 971

U. S. DEPARTMENT OF AGRICULTURE
Washington, D. C.
1955

CONTENTS

	Page
Materials and equipment factors	2
Types of aromatic solvents	2
Types and concentrations of emulsifiers	3
Equipment for application	4
Measurements and calibrations	8
Rate of application	10
Channel and water factors	13
Size of channel	13
Turbulence and agitation of water	13
Velocity of water	14
Temperature of water	14
Turbidity and salt content	15
Weed-growth factors	15
Stage of growth	15
Distribution and density	16
Susceptibility of species	16
Control period	17
Toxicity of aromatic solvents	21
Toxicity to submersed aquatic weeds	21
Toxicity to crop plants	21
Toxicity to soil bacteria	28
Toxicity to farm animals	28
Toxicity to fish and other aquatic animal life	29
Cost of materials and application	29
Precautions	29
Summary and conclusions	31
Literature cited	32

Washington, D. C. Issued October 1955

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 20 cents

The Use of AROMATIC SOLVENTS for Control of Submersed Aquatic Weeds in Irrigation Channels

By V. F. Bruns, Associate Agronomist; J. M. Hodgson, Associate Agronomist; H. F. Arle, Associate Plant Physiologist; and F. L. Timmons, Senior Agronomist; Field Crops Research Branch, Agricultural Research Service.[1]

Submersed aquatic weeds have caused numerous and often serious problems in water-distribution and drainage systems in the irrigated sections of the Western States. They have frequently interfered, directly or indirectly, with delivery of irrigation water. They have also increased losses from seepage and evaporation and have contributed to collection of silt, canal breaks, and other difficulties (*4*, *10*, *12*, *14*).[2] Problems of this nature occur most often and are most serious during the warm growing season when irrigation water is urgently needed for crops. From surveys in 1947–48, Balcom (*4*) reported that irrigation-water losses resulting from aquatic and ditchbank weeds in the 17 Western States were estimated at 1,272,480 acre-feet annually, with a value of nearly $25½ million.

The majority of these aquatic weeds are rooted in soil in the bottom and sides of irrigation channels and grow almost entirely beneath the water surface. Most of them are species of the genus *Potamogeton*, and are commonly called moss or horsetail moss.

Various methods, such as draining and drying, hand-cleaning, chaining, and dredging for the control of submersed aquatic weeds in irrigation channels, have been used extensively and with considerable success (*6*, *8*, *14*). In many situations, however, these methods have proved relatively inefficient, or cumbersome, time-consuming, and expensive, especially in smaller channels.

Copper sulfate and chlorinated benzene compounds (*5*, *14*) were among the first chemicals used to control submersed aquatic weeds. Copper sulfate was found effective on certain species of algae, but it was not generally effective on plants that were rooted in the bottom of the channel. Chlorinated benzene gave effective control of rooted submersed aquatic weeds and was used fairly extensively for that purpose as early as 1944.

In 1947 (*12*), personnel of the United States Bureau of Reclamation and the United States Bureau of Plant Industry, Soils, and Agricultural Engineering, working cooperatively at Denver, Colo., discovered

---

[1] Report of cooperative investigations of the Field Crops Research Branch, Agricultural Research Service; the State agricultural experiment stations in Washington, Idaho, Arizona, and Utah; the U. S. Department of the Interior, Bureau of Reclamation; the Ada County Weed Control Department, Meridian, Idaho; and the Salt River Valley Water Users Association, Phoenix, Ariz. Several private irrigation districts furnished channels, equipment, materials, and personnel for many of the experimental trials.

[2] Italic numbers in parentheses refer to Literature Cited, p. 32.

the effectiveness of certain aromatic solvents [3] as waterweed killers. Further trials and usage during 1948 resulted in the issuance of a joint report (*13*) which outlined specific procedures and tentative recommendations for the use of these materials.

During 1947–52, extensive experimental tests using aromatic solvents for submersed aquatic weed control were conducted near field stations located at Prosser, Wash.; Meridian, Idaho; Phoenix, Ariz.; and Logan, Utah. A total of 153 separate irrigation channels were treated experimentally with aromatic solvents on a field-scale basis. In addition, the effects of herbicidal concentrations of these materials on various crop plants and on animal life were investigated.

The purpose of this publication is to consolidate and disseminate the information that was accumulated at the 4 field stations during the 6-year period. Because the investigations included many different phases and procedures, the materials, methods, results, and applications of results are discussed together under the appropriate topics.

MATERIALS AND EQUIPMENT FACTORS

Types of Aromatic Solvents

The specifications for the types of aromatic solvents to be tested for aquatic weed control (table 1) were established at the United States Bureau of Reclamation Chemical Engineering Laboratories, Denver, Colo., in 1947–48 (*12*, *13*).

TABLE 1.—*Specifications for the types of aromatic solvents to be tested for aquatic weed control*

Solvent detail	Requirements for—	
	Type A	Type B
Flashpoint not less than ° F	80	80
ASTM D 86 (*1*) distillation:		
Starting point ° F	278	275
Not more than 10 percent ° F	286	
Not less than 90 percent ° F	395	333
End point, not higher than ° F	420	360
ASTM D 875 (*2*) aromatic content:		
Not less than Percent	85	75

Since type A solvents were generally more effective than type B solvents in the laboratory screening tests, the former were used almost exclusively in the field investigations reported here. Aromatic solvents of both petroleum and coal-tar origin were included.

[3] Aromatic solvents are commonly used in industry as paint thinners, because of their solvent properties. The materials used in these tests for killing submersed waterweeds actually were mixtures of aromatic or cyclic hydrocarbons of either petroleum or coal-tar origin and had the general specifications listed in the next section.

In general, type A solvents from either petroleum or coal tar were effective in controlling submersed aquatic weeds when properly used at an optimum concentration and introduction time. Throughout the course of these experiments, however, there was variation in effectiveness between different commercial products and even between products obtained from the same source. When completely unsatisfactory results were obtained from a treatment at an optimum rate, the cause could usually be traced to one or both of two factors—either the solvent failed to meet type A specifications, or it contained an insufficient quantity of a suitable emulsifier. In these field trials, no study was made of the specific fractions and other properties of aromatic solvents that gave the most satisfactory results. Additional laboratory studies on this particular phase are needed.

A mixture of equal parts of polychlorobenzene and aromatic solvent gave less satisfactory results than comparable rates of aromatic solvent in 6 tests at 2 field stations, although exceptionally uniform dispersion of the chemical in the water was readily attained. Mixtures of aromatic solvent and chlorinated hydrocarbons, as well as other chemicals and mixtures, are being investigated further for effectiveness in controlling aquatic weeds.

Aromatic solvents commercially available as aquatic weedkillers are not usually labeled according to specifications and should therefore be purchased from reliable sources.

Types and Concentrations of Emulsifiers

In these studies, aromatic solvents, which are insoluble in water, were emulsified with the water in the channel for control of submersed aquatic weeds. The emulsifiers were added to and thoroughly mixed with the solvent prior to the introduction of the materials into the streams. Creating a good emulsion or suspension of solvent in irrigation water was found to be one of the most important factors in the success of the treatment. When an unsatisfactory emulsion was obtained, the solvent separated from the water, rose to the surface, evaporated, and caused little or no perceptible damage to the weed growth. Conversely, an equable, milky appearance throughout the cross section of the streamflow indicated a good emulsion, and satisfactory weed control usually resulted (fig. 1).

Oil- and water-soluble petroleum sulfonates (mahogany soaps), at 5 to 10 percent by volume of solvents, were used as emulsifying agents during the early stages of these investigations (*13*). Satisfactory results were generally obtained with these emulsifiers for distances ranging from ⅓ to 2 miles of channel per treatment. However, experience showed that the performance of this type of emulsifier was affected adversely by lower temperatures or higher salt content of the water.

The advent and use of nonionic type emulsifiers, beginning in 1949, increased the overall efficiency of the applications. Nonionic emulsifiers do not react with hard waters since they do not ionize in solution. In some regions these emulsifiers resulted in satisfactory treatments of channels for distances of 5 miles or more below the point of application. Under the wide range of conditions in which these emulsifiers were tested and used, 2-percent nonionic emulsifier by

Figure 1.—A good emulsion of aromatic solvent in an irrigation channel 200 yards below the point of introduction. (An emulsion is a suspension of one liquid uniformly dispersed in another liquid.)

volume of solvent appeared to give optimum results. Commercial aquatic herbicides, consisting of aromatic solvents and containing nonionic emulsifiers, were readily available after 1949 and, in general, gave satisfactory results in field tests.

Equipment for Application

Aromatic solvents containing emulsifiers were introduced into the channels with the spray nozzles under water. Conventional type spray equipment with gear pumps and fine-spray nozzles were used in making most of the experimental applications. However, many types of spraying units, ranging in size from ½-inch gear pumps with small spray booms through orchard sprayers with piston pumps and orchard guns to large centrifugal pumps with fire-hose nozzles, have been used successfully for experimental applications of aromatic solvents as well as in practical control programs by various irrigation districts (figs. 2, 3, 4, 5).

Although various types of nozzles at pressures ranging from 50 to 100 p. s. i. (pounds per square inch) gave good results, dispersion of chemicals in water and stability of emulsions were increased in some instances by the use of smaller orifice nozzles and higher pressures.

In 1949 the Sunnyside Valley Irrigation District, Wash., developed an inexpensive double suction unit for applying aromatic solvents (fig. 5).[4] The main 4-inch suction line drew water from the channel

[4] Brooks, D. C. SUNVALID SOLVENT SYSTEM. Sunnyside Val. Irrig. Dist., Sunnyside, Wash. 3 pp., illus. 1951. [Processed.]

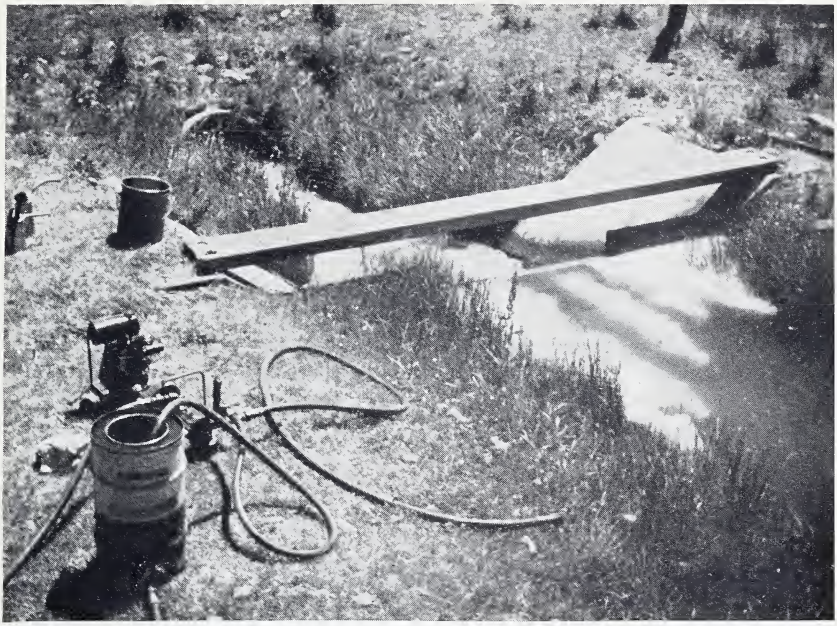

Figure 2.—A simple unit for introducing aromatic solvent, consisting mainly of a small gasoline engine, a ½-inch gear pump, and a boom with fine-spray nozzles.

Figure 3.—A trailer-mounted unit for introducing aromatic solvent. A gasoline engine, ¾-inch gear pump, and spray boom with nozzles are the main features.

Figure 4.—A conventional type sprayer with orchard gun, used for applying aromatic solvent.

to be treated, and a second 1½-inch suction line drew the solvent mixture from a measured container. In this manner the water and solvent were drawn together into the pump casing, thoroughly mixed, and discharged under a pressure of 200 p. s. i. into the channel through a large hose with a fire-hose nozzle. This system proved to have several advantages: (A) Clogging of small-orifice nozzles by foreign particles was eliminated. (B) The churning action of the pump impeller which thoroughly mixed the water and solvent, together with the discharge of the mixture under high pressure, resulted in a much more stable emulsion. (C) Introduction could be made at any location in a channel without regard to weirs or other turbulence-creating structures which were normally used to advantage in promoting dispersion of the aromatic solvents. (D) Channels with a wide range in capacities could be treated at the desired rate by merely adjusting the flow of solvents to the pump.

The Wapato Irrigation Project in Washington used a modification of this system. A meter from a gasoline pump was installed in the line between the spray pump and the solvent supply tank. The limited capacity of the meter and the pump restricted the use of this equipment to small laterals. This restriction may be eliminated through the use of larger meters, pumps, and supply tanks.

Natural or reclaimed rubber and petroleum greases are dissolved rapidly by aromatic solvents. Experience proved that solvent-resistant hoses, gaskets, washers, and greases were essential parts of the spray equipment.

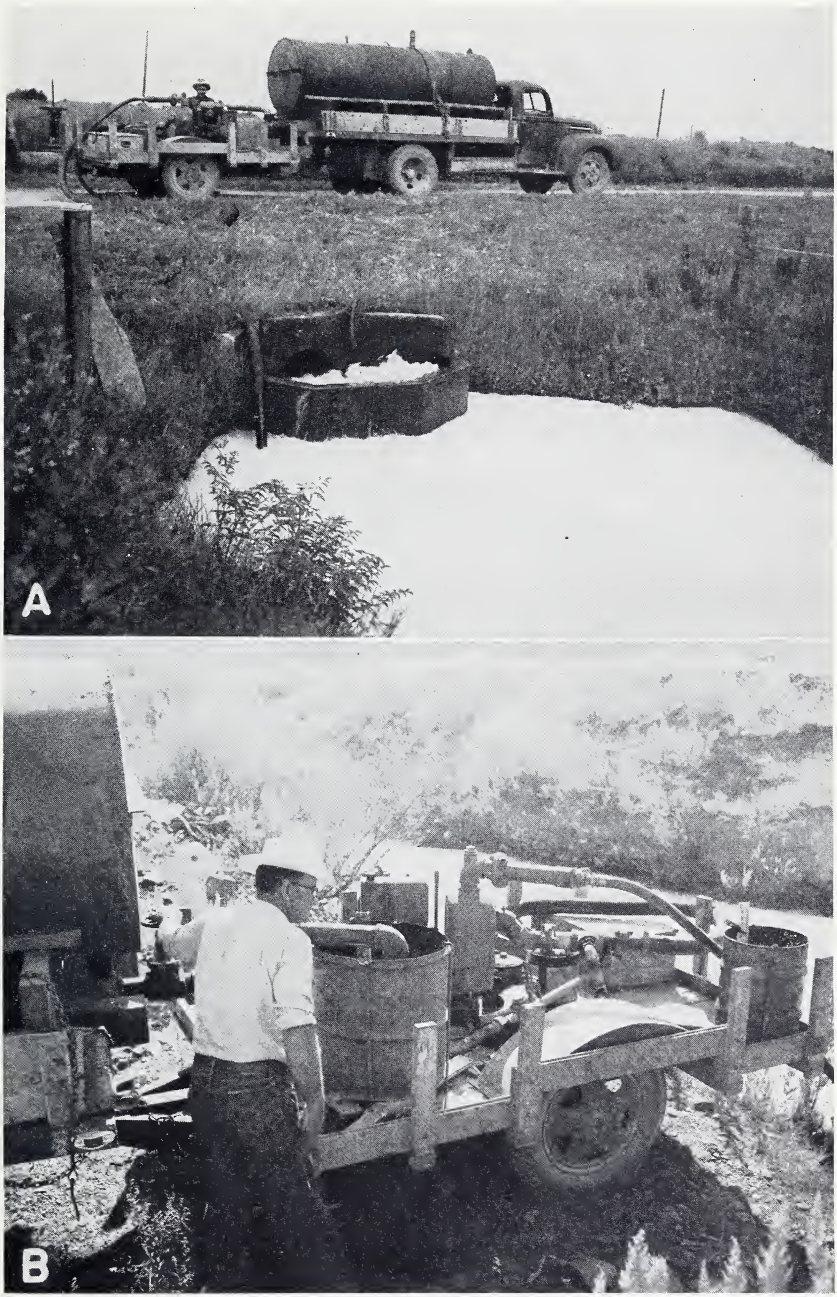

Figure 5.—A large unit developed for applying aromatic solvent: *A*, A 1,000-gallon tank mounted on a truck supplies solvent for the pumping unit mounted on a trailer. *B*, Water from the ditch through a 4-inch hose and solvent from the supply tank via a calibration drum are drawn into the pump casing, and the mixture is discharged under pressure into the stream through a 2-inch hose with a fire-hose nozzle.

347152°—55——2

Measurements and Calibrations

An accurate measurement of the flow of water in the channel was essential in determining the quantity of chemical to apply over a given period of time in order to obtain the desired concentration. Since fluctuations occurred frequently, measurement of the flow of water immediately before treatment was advantageous. The flow of water in many delivery channels was measured by relatively accurate weir gages or similar devices (fig. 6). In the absence of such measuring devices, the approximately flow of water was computed by determining as accurately as possible the cross-sectional area of the stream and the velocity of the flow. The following formula was used:

Average width in feet × average depth in feet × mean velocity in feet per second = cubic feet per second.

Figure 6.—Weir and gage for measuring discharge.

Approach pools occasionally were infested heavily with aquatic weeds which caused a turbulent flow of water over the weir. In such cases a correction in the quantity of waterflow as determined from the gage-height reading was desirable. The following method for approximate correction was found useful:

Determine Q (quantity) from gage reading (R).
Determine Va (velocity) from $Q \div A$ (A = length of weir × R.)

$$Hv \text{ (velocity head)} = \frac{Va^2}{64.4}$$

Add Hv to observed R.
Determine corrected Q from corrected R.

Dead water pockets sometimes occur in irregular channels and cause excessive dilution of the concentrations of solvent. In such instances, the quantity of solvent should be increased to compensate for the dilution.

The practice of reducing the waterflow during treatments was employed in some experimental treatments, and its use in commercial treatments was observed frequently. This practice was justifiable in some instances because less chemical was required to obtain the desired concentration. In other instances, a reduction in flow of water proved highly undesirable because of the resultant massing and compacting of weed growth, especially along the sides of the channels near the surface

Figure 7.—The waterflow was inadvertently reduced during this application. Note the channeling of treated water along one side of the massed weed growth.

of the water. With such massing and compacting, the major portion of the treated water tended to channel through or bypass dense infestations without coming in contact with much of the weed growth (fig. 7). Aromatic solvents were most effective when the flow was sufficient to permit free circulation of treated water among the plants.

After the flow of water in the channel to be treated was determined accurately, the spray equipment was calibrated and adjusted to apply the correct quantity of solvent materials over a desired period of time. Manufacturers usually supply tables which indicate the discharge capacity of their conventional type spray nozzles under various pressures. These tables were used for approximations only and actual test runs were made with the solvent materials to be applied. With conventional type sprayers and nozzles, the delivery of each nozzle

Figure 8.—Equipment used for measuring the rate of discharge of spray nozzles.

was determined by catching the spray in containers during a period of 1 minute (fig. 8). The measured amounts multiplied by the number of minutes for the treatments gave the delivery of each nozzle for the treatment period (*10*). If adjustments were necessary, a change in nozzle size or pressure usually sufficed. Calibration of the equipment with water rather than with the solvent to be applied was found to be inaccurate.

RATE OF APPLICATION

To determine the optimum rates for controlling various species of submersed aquatic weeds, aromatice solvents were tested in irrigation channels at different concentrations for different periods of time, ranging from 181 parts per million (p. p. m.) for 92 minutes to 2,400 p. p. m. for 5 minutes. The rate of application, or number of gallons of solvent per cubic foot per second (c. f. s.) of flow of water, is determined by the concentration and the length of application period. Simple methods of calculation have been outlined in earlier publications (*9*, *11*, *13*). The following formulas were used most frequently:

$$\text{P. p. m.} = \frac{\text{Number of gallons of solvent} \times 1{,}000{,}000}{\text{Number of c. f. s.} \times 450 \times \text{time in minutes}}$$

$$\text{Gallons of solvent per c. f. s.} = \frac{450 \times \text{time in minutes} \times \text{p. p. m.}}{1{,}000{,}000}$$

$$\text{Total gallons of solvent} = \frac{450 \times \text{minutes} \times \text{p. p. m.} \times \text{c. f. s.}}{1{,}000{,}000}$$

The rates of application found to be most effective were dependent upon a number of factors, such as species, density, and distribution of weeds; temperature, salinity, and velocity of waterflow; and the length of the channel. Comparable data which are indicative of the results from a portion of the tests during 1950 are presented (tables 2 and 3). A condensed summary of the data which were collected under a wide range of conditions during the 6-year period of these investigations showed the following general trends:

TABLE 2.—*Effects of concentration of aromatic solvents* [1] *and introduction time on the control of submersed aquatic weeds in irrigation channels at Prosser, Wash., 1950*

Kinds of pondweed present	Amount of chemical applied		Introduction time	Distance from introduction point	Control after—	
					2 weeks	8 weeks
	P.p.m.	*Gal./c.f.s.*	*Minutes*	*Miles*	*Percent*	*Percent*
Gigantic Sago, Richardson, Leafy	300	4.05	30.0	¼	65–70	20–25
				½	60–65	20–25
				¾	60–65	20–25
Gigantic Sago, Richardson, Leafy	400	5.40	30.0	¼	———	60–70
				½	90–95	60–70
				¾	———	60–70
				1	95–100	60–70
				1½	80–90	60–70
Gigantic Sago	600	8.10	30.0	¼	90–95	90–95
				½	85	85–90
				¾	85	85–90
Gigantic Sago, Richardson, Leafy	800	5.40	15.0	¼	———	95–100
				½	———	[2] 75
				¾	———	90–95
				1	75–80	50–60
Gigantic Sago, Richardson	1,600	5.40	7.5	¼	90–100	60
				½	———	30–35
				¾	100	90–95
				1	———	95–100
Gigantic Sago, Richardson, Horned	2,400	5.40	5.0	¼	75–80	5–10
				½	85–90	50
				¾	90–95	90–95

[1] Type A petroleum aromatic solvent containing 2 percent nonionic emulsifier.
[2] Aquatic weed growth exceptionally dense.

(1) A concentration of 150 p. p. m., introduced over a 15-minute period (1 gallon per c. f. s.), was sufficient to control filamentous green algae in channels up to 2½ miles in length.

(2) A concentration of 300 p. p. m., introduced over a 30-minute period (4.05 gallons per c. f. s.), was not completely effective on most rooted species of aquatic weeds.

(3) Introductions of 400 to 440 p. p. m. over a 30-minute period (5.4 to 5.9 gallons per c. f. s.) were effective on such species as leafy, sago, and horned pondweeds for distances of ¾ to 1½ miles of channel. However, the control periods from such applications did not

TABLE 3.—*Effects of concentration of aromatic solvents* [1] *and introduction time on the control of submersed aquatic weeds in irrigation channels at Meridian, Idaho, 1950*

Kinds of pondweed present	Amount of chemical applied		Introduction time	Distance from introduction point	Control	Control period
	P. p. m.	*Gal./c. f. s.*	*Minutes*	*Miles*	*Percent*	*Weeks*
Sago	400	5. 40	30. 0	¾	75–80	5
Leafy	400	5. 40	30. 0	¾	70–80	5
Sago	400	5. 40	30. 0	1	70–80	6
Sago	460	6. 21	30. 0	¾	70	5
Sago and leafy	500	6. 75	30. 0	1	98	7
Sago and leafy	800	5. 40	15. 0	1	80–90	6½
Leafy and horned	800	5. 40	15. 0	¾	40–50	3
Horned	815	5. 50	15. 0	½	98	(2)
Leafy	1, 000	6. 75	15. 0	1	98	(2)
Horned and leafy	1, 650	5. 57	7. 5	¾	60–70	5
Sago	2, 400	5. 40	5. 0	½	60–80	
				¾	60–70	5
Sago, leafy, and horned	2, 400	5. 40	5. 0	¾	40–50	3
Sago and leafy	2, 400	5. 40	5. 0	½	30–40	2

[1] Type A petroleum aromatic solvent containing 2 percent nonionic emulsifier.
[2] Season.

usually exceed 5 to 6 weeks, and re-treatments were frequently necessary, especially if such species as gigantic sago and Richardson pondweeds were present.

(4) The results from introductions of 200 to 220 p. p. m. over a 1-hour period (5. 4 to 5.9 gallons per c. f. s.) were similar to those from 400 to 440 p. p. m. for 30 minutes.

(5) Introductions of 600 p. p. m, over a 30-minute period (8.1 gallons per c. f. s.) in laterals up to 2 miles in length usually gave effective control of certain species for periods of 8 weeks or longer. This rate of application was generally recommended for use in channels that were infested with the somewhat less resistant species, such as leafy and horned pondweeds.

(6) A concentration of 740 p. p. m., introduced over a 30-minute period (10 gallons per c. f. s.), frequently gave adequate control of aquatics for the entire irrigation season, including the more resistant species such as gigantic sago and Richardson pondweeds. This rate of application was generally recommended and used where the more resistant species were present or where the channels to be treated were of considerable length. Effective control of submersed aquatics for distances up to and greater than 5 miles without booster applications was common. With lower concentrations, booster applications downstream from the initial station were sometimes necessary in order to maintain a killing concentration in lengthy channels.

(7) A concentration of 800 p. p. m. over a 15-minute period (5.4 gallons per c. f. s.) gave effective control of most species over an 8-week period for a distance of only ¾ miles in the channel.

(8) A concentration of 1,600 p. p. m. over a 7½-minute period (5.4 gallons per c. f. s.) was not effective in the first ¼ to ½ mile downstream but was highly effective in the section ¾ to 1 mile from the point of introduction. This indicates that the treatments were less effective until the blanket [5] had lengthened considerably and increased the exposure time downstream. Although the concentration was reduced as the blanket lengthened, the initial high concentration apparently was not reduced below a lethal dosage after traveling a distance of ¾ mile to 1 mile.

(9) The results from the introduction of 2,400 p. p. m. over a 5-minute period (5.4 gallons per c. f. s.), frequently called the "slug method," were similar to those obtained from 1,600 p. p. m. over a 7½-minute period, with the poor results (apparently from insufficient contact time) being even more pronounced.

(10) Because of variation in water and in plant growth, higher rates of solvent may be required for controlling submersed aquatic weeds in some areas than in others. Results of these tests showed that comparable rates were less effective in Arizona than in the Pacific northwest, especially in channels in Arizona which carried pump water.

CHANNEL AND WATER FACTORS

Size of Channel

The flow of water in the channels that were used most frequently for experimental applications of aromatic solvents ranged from 1 to 6 cubic feet per second (c. f. s.). However, successful commercial applications were made in canals with flows ranging up to 150 c. f. s. (*7*). With respect to size, channels that may be treated with aromatic solvents apparently are limited by two major factors: Capacity of available spraying equipment; and cost of materials and application in comparison with cost of mechanical or other means of control.

Turbulence and Agitation of Water

Thorough dispersion of the chemicals in the water before coming into contact with weed growth was of utmost importance. Aromatic solvents are lighter than water. Unless completely dispersed, the emulsions did not extend to the bottom of the channel but tended to break up more rapidly, allowing the solvent to rise to the surface and evaporate.

With conventional spray units, the introduction of chemicals immediately above a weir or other structure, with a considerable drop and turbulent pool, usually promoted adequate dispersion (fig. 9). In the absence of such structures, compressed-air booms, attached to large compressor units and placed in the water immediately below the spray boom, provided agitation and chemical dispersion. The advantage of mixing the aromatic solvents with water prior to introduction under high pressure has already been discussed in the section titled "Equipment for Application".

---

[5] Blanket, a term commonly used, refers to the readily visible milky emulsion formed by the aromatic solvent and emulsifier in the flowing water in the channel.

Figure 9.—Introduction of aromatic solvent just above the weir, and turbulent weir pool which promoted dispersion of the chemical in the water.

Velocity of Water

Velocities of the flow of water and irregularities in channels affecting velocity were observed to influence appreciably the effectiveness of aromatic-solvent treatments. Although the emulsion blanket was carried for greater distances, high velocities (1.3 f. p. s. or greater) tended to reduce the effectiveness of the treatments, especially near the bottom of the channel, and recovery of aquatic weed growth was usually rapid. In slow-moving water (0.5 f. p. s. or less), the treatments gave excellent control, but the distances that the effective emulsions were carried were reduced greatly. Optimum results were usually obtained when the velocity of the flow of water was between 0.75 and 1.25 f. p. s.

Temperature of Water

Aromatic solvents were tested in different channels under a wide range of water temperatures (58° and 88° F.). Satisfactory results were often obtained in the low range of water temperatures, especially when nonionic emulsifiers were used. However, with other factors approximately equal, better results with comparable rates of aromatic solvent were obtained in channels with higher water temperatures. Although the use of aromatic solvents is not precluded at lower temperatures, optimum results may be expected when water temperatures are 70° F. or above.

Turbidity and Salt Content

Submersed aquatic weed growth is generally inhibited in water that is continuously turbid or muddy (high percentage of suspended soil particles). In most delivery channels, however, marked turbidity may occur only infrequently or intermittently, and aquatic weed growth remains a serious problem.

Tests showed that aromatic solvents were much less effective when applied in highly turbid or muddy water. Suspended soil particles not only tended to cover plant growth with a protective silty scum but also seemed to absorb quantities of the solvent materials. Slight turbidity did not seriously impair the effectiveness of the treatments.

As mentioned previously, aromatic solvents were comparatively less effective in the control of submersed aquatics in the Southwest, particularly Arizona, than in other regions. Since the addition of salts has been used industrially for a number of years for cracking certain emulsifying films, it seems possible that the high salt concentrations in pump water in Arizona and other areas having similar water quality may have been the cause of the less satisfactory results with aromatic solvents in those areas.

WEED-GROWTH FACTORS

Stage of Growth

Best results were obtained with solvent treatments which were applied as soon as weed growth began to interfere noticeably with the flow of water but before the plants had reached the surface of the water. Usually, one completely effective treatment at this stage of development was sufficient for the season, except in regions with year-round or long periods of irrigation. Weed growth was somewhat more susceptible earlier in the season, but treatments made at this time often permitted rapid regrowth, and re-treatments were frequently necessary. On the other hand, comparable rates of aromatic solvents were much less effective on aquatics which had reached an advanced or nearly matured stage of development.

Under prudent management, it was sometimes possible to decrease the flow of water before treatment and reduce the amount of chemical needed for control when treatments were made before the weed growth became too rank and reached the water surface. In general practice, the development and distribution of weed growth throughout all portions of the channel should be checked carefully by competent personnel to determine whether or not a reduction in the flow of water prior to treatment is feasible. Accurate adjustments should then be made accordingly. A flow sufficient to permit free circulation of treated water among plants in all infested sections of the channel is highly important. When weed growth was at a proper stage for treatment, some irrigation districts, particularly in the Boise Valley of Idaho, found reductions in the flow of water prior to applications in certain channels to be advantageous, while other irrigation districts, particularly in the Yakima Valley of Washington, found it more practical and effective to treat channels, especially smaller laterals, without decreasing the flow of water.

347152°—55——3

From a practical standpoint, the number of channels or miles to be treated and the equipment available would largely determine when solvent treatments should be started. The last of the channels should be treated before the weeds have reached an advanced stage of development, even though earlier treatments may have to be repeated before the end of the season.

Distribution and Density

The distribution and density of the weed growth in the treated channels had pronounced effects on the results obtained. Solvent treatments were most effective in channels where weed growth was evenly distributed and only sparsely or moderately dense. The treatments were least effective in channels with heavy stands and dense growth which frequently occurred in localized sections (fig. 10). In such areas, the treated water tended to pass over the top of the dense growth with the main portion of the current, and inadequate dispersion of treated water into the weed mass was obtained. The importance of treating channels with this type of growth before an advanced stage of development is strongly emphasized.

Figure 10.—A dense stand and growth of submersed aquatic weeds infesting an irrigation channel.

Susceptibility of Species

Susceptibility of species to aromatic solvents varied somewhat from region to region, depending considerably on local conditions. General ranges for several species of *Potamogeton* (horsetail moss), and for a few other aquatic weeds, are given (table 4).

TABLE 4.—*Rates of aromatic solvent usually needed to control different species of submersed aquatic weeds*

Species	Usually controlled with—		
	Concentration	Introduction time	Amount of solvent
	P. p. m.	*Minutes*	*Gal./c. f. s.*
Filamentous algae	150	15	1. 0
White watercrowfoot (*Ranunculus aquatilis* L.)	300–400	30	4. 0–5. 4
Waterweed (*Anacharis canadenis* (Michx.) Planchon)	400–600	30	5. 4–8. 1
Horned pondweed (*Zannichellia palustris* L.)	400–600	30	5. 4–8. 1
Leafy pondweed (*Potamogeton foliosus* Raf.)	400–600	30	5. 4–8. 1
Sago pondweed (*P. pectinatus* L.)	600	30	8. 1
Richardson pondweed (*P. richardsonii* (Benn.) Rydb.)	740	30	10. 0
Gigantic sago pondweed (*P. pectinatus* var. *interruptus* (Kit.) Aschers.)	740	30	10. 0
American pondweed (*P. nodosus* Poiret)	740	30	10. 0
Water stargrass (*Heteranthera dubia* (Jacq.) MacM.)	740 or more	30	10. 0 or more

Under certain adverse conditions, somewhat greater concentrations were occasionally required to give complete control of the various species. The greater resistance of some species to solvent treatments probably resulted in part from differences in morphological structure, such as heavier stems (*P. richardsonii*); heavier stems and floating leaves (*P. nodosus* and *H. dubia*); and coarser, filiform type of leaves (*P. pectinatus* var. *interruptus*) (fig. 11).

A definite change in vegetative composition was noted in several channels that had been treated with aromatic solvents during each of the first 2 or 3 years of these investigations. The lighter concentrations of aromatic solvents used initially reduced the more susceptible species (figs. 12, 13) and permitted the more resistant species to become dominant. This clearly demonstrated the necessity for using a sufficiently high concentration to control effectively all species which may occur in the channel to be treated.

Control Period

The treatments with aromatic solvents were not appreciably injurious to the perennial root systems of the submersed aquatic weeds. The control of weeds was temporary or seasonal, permitting unimpeded flow of water through the channels during a major portion of the season. In most cases, the extent and density of weed regrowth the following year was comparable to the original infestation. However, any effective control practice should eventually reduce weed populations, if conducted persistently and systematically over a sufficient length of time.

Figure 11.—*A*, American pondweed (*Potamogeton nodosus* Poiret); *B*, gigantic sago pondweed (*P. pectinatus* var. *interruptus* (Kit.) Aschers.); C, Richardson pondweed (*P. richardsonii* (Benn.) Rydb.).

Figure 12.—White watercrowfoot (*Ranunculus aquatilis* L.)

Figure 13.—*A*, Horned pondweed (*Zannichellia palustris* L.); *B*, waterweed (*Anacharis canadensis* (Michx.) Planchon); *C*, leafy pondweed (*Potamogeton foliosus* Raf.).

As stated in an earlier section (p. 12), one completely effective treatment was frequently sufficient to prevent weeds from interfering with water delivery for one season, except in regions with year-round or exceptionally long periods of irrigation. In some instances, especially when the first applications were not completely effective, regrowth of pondweeds was noticeable within 2 or 3 weeks and retreatments were necessary within 4 to 8 weeks. Some species recovered more rapidly than others after a treatment. Gigantic sago pondweed appeared to be one of those species.

TOXICITY OF AROMATIC SOLVENTS

Toxicity to Submersed Aquatic Weeds

The reaction and appearance of weed growth after treatment with aromatic solvents varied considerably with the different solvents and emulsifiers used, with the different species of weeds present, and with different temperatures of water. Generally, foliage turned a dark color (dark green to dark brown or almost black) within a few hours after the application. Some materials caused foliage on certain species to turn nearly white—indicative of almost complete removal of chlorophyll.

Within 24 to 48 hours after treatment, plants became flaccid and began to settle to the bottom of the channel. At the same time, a significant drop in the water level was noted. After 2 or 3 days, plants usually settled almost completely to the bottom of the channel, turned lighter in color, and gradually disintegrated or "sloughed off" without clogging irrigation structures downstream. The most effective treatments killed all top growth to the silt line and tended to prevent regrowth for several weeks after the application (fig. 14).

Toxicity to Crop Plants

In greenhouse tests at Prosser, Wash. (*3*, *14*), soil applications of aromatic solvent (xylol) at rates within the range recommended for submersed aquatic weed control caused no injury to potted lettuce, lima beans, Ladino white clover, or orchard grass.

With special plots and techniques designed for these studies, aromatic solvents at various rates in irrigation water were applied to different crops by either furrow- or flood-irrigation at Meridian, Idaho, and Phoenix, Ariz., 1948–51. At Meridian, a designated concentration of solvent was introduced into a main head ditch from which the treated water was applied to the plots through 2-inch siphon tubes for a designated period of time. Small waste ditches at the ends of the plots were used for disposal of runoff water during furrow-irrigation treatments. The average slope of the land was less than 0.5 percent. At Phoenix, plots 10 feet wide and 30 feet long were laid out along small irrigation canals. Each plot was diked sufficiently to permit flood irrigation. Water containing a specified concentration of aromatic solvent was allowed to flow through 1½-inch pipes from the irrigation canals onto the plots for 40 minutes, during which period the equivalent of 3 acre-inches of treated water was delivered.

Crops included in the furrow-irrigation tests were Netted Gem potatoes, hybrid sweet corn, Red Mexican beans, sugar beets, and carrots. Crops included in the flood-irrigation experiments were Idaed spring wheat, Overland oats, Chilean alfalfa, Acala 33 cotton, and Plainsman grain sorghum. Treatments were replicated from 3 to 6 times. Comparable yield data from these experiments are presented (tables 5 and 6).

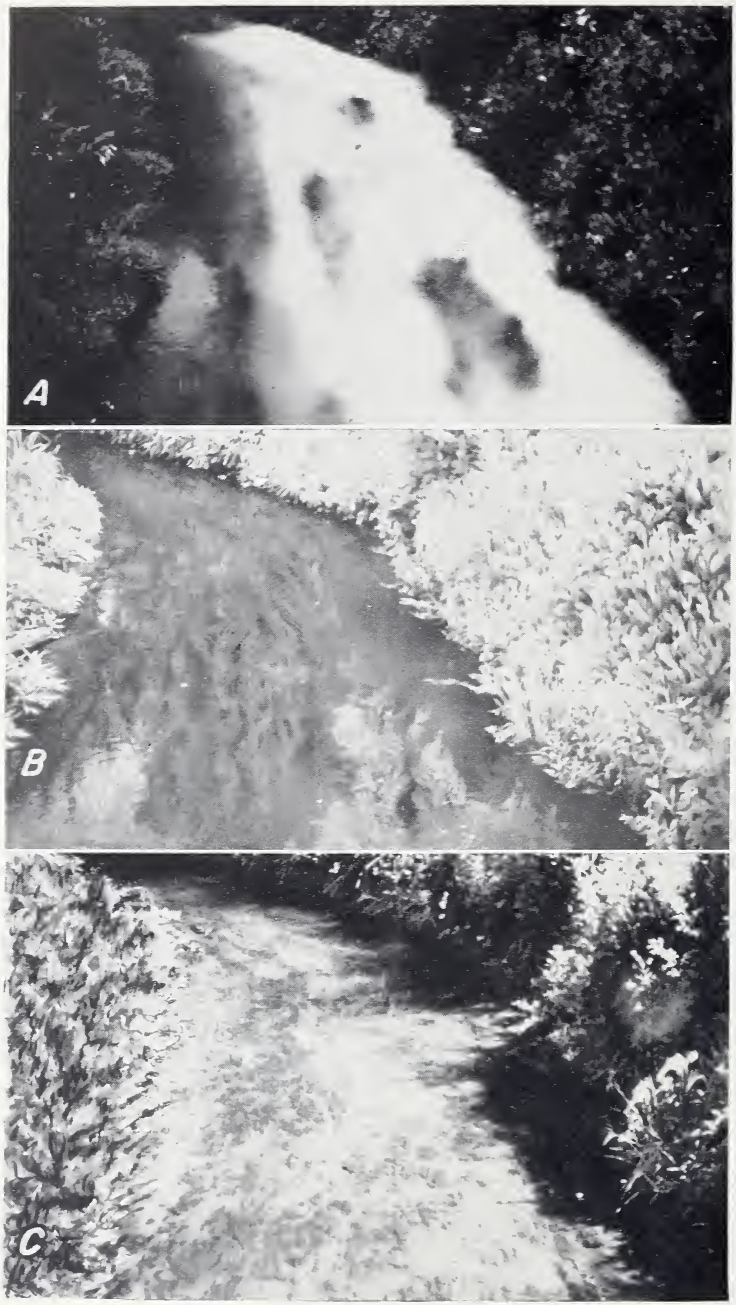

Figure 14.—The effects of aromatic solvent on submersed aquatic weeds in an irrigation channel: *A*, During treatment; *B*, 3 days after treatment; *C*, 2 weeks after treatment.

TABLE 5.—*Crop yields, expressed as percentages of check-plot yields, as influenced by single irrigations with water containing different concentrations of aromatic solvent. Experiments conducted at Meridian, Idaho, 1948–51*

Year	Application (30-minutes)		Crop and stage of growth when treated [1]						
			Spring wheat, late-boot	Sweet corn, silking	Potatoes, early-bloom	Sugar beets, 2-in. diameter	Red Mexican beans, early-bloom	Oats, heading	Carrots, ½-in. diameter
	P. p. m.	*Gal./c.f.s.*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1948	600	8. 1	98						
	1, 200	16. 2	103						
	2, 200	29. 7	78						
	Check		100						
1949	400	5. 4		112	116	106	[2] 92		
	800	10. 8		116	120	103	98		
	1, 200	16. 2		110	98	107	105		
	Check			100	100	100	100		
1950	800	10. 8		104	76	75	86		
	1, 200	16. 2		102	106	100	102		
	1, 600	21. 6		88	109	86	92		
	[3] 2, 400	10. 8		104	99	64	82		
	Check			100	100	100	100		
1951	800	10. 8				103	[4] 89	105	106
	1, 200	16. 2				101	99	99	91
	1, 600	21. 6				99	81	108	95
	2, 400	32. 4				106	105	106	91
	Check					100	100	100	100

[1] Spring wheat and oats were flood-irrigated; all other crops were furrow-irrigated.
[2] Weights of shelled beans were used as a criterion for yields of Red Mexican beans, 1949–50.
[3] 2,400 p. p. m. applied for 10 minutes.
[4] Weights of both tops and beans were used as a criterion for yields of Red Mexican beans, 1951.

TABLE 6.—*Crop yields, expressed as percentages of check-plot yields, as influenced by single flood-irrigations with 3 acre-inches of water containing different concentrations of aromatic solvent. Experiments conducted at Phoenix, Ariz., 1949–51*

Year	Application (40 minutes)		Crop and stage of growth when treated				
			Grain sorghum—				Alfalfa, 3 in. seedling
			Seedling	14 in. high	Boot	Bloom	
	P. p. m.	*Gal./ c. f. s.*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1949	400	7. 2	85	93	92	97	105
	800	14. 4	87	98	88	101	116
	Check	----	100	100	100	100	100

Year	Application (40 minutes)		Grain sorghum—		
			6–8 in. high [1]	6–14 in. high	Early-boot
	P. p. m.	*Gal./ c. f. s.*			
1950	400	7. 2	102	105	91
	800	14. 4	91	105	100
	1, 600	28. 8	86	107	100
	Check	----	100	100	100

Year	Application (40 minutes)		Cotton—			2d-year alfalfa, after cutting of previous crop
			Early-square	Early-bloom	1st bolls matured	
	P. p. m.	*Gal./ c. f. s.*				
1950	400	7. 2	94	102	90	94
	800	14. 4	81	93	95	100
	1, 600	28. 8	95	95	82	112
	Check	----	100	100	100	100

Year	Application (40 minutes)		Cotton—		Grain sorghum—1st, 3d, and 5th irrigations
			10-12 in. high	24–30 in. high	
	P. p. m.	*Gal./ c. f. s.*			
1951	400	7. 2	95	100	96
	800	14. 4	97	96	96
	1, 600	28. 8	94	96	[2] 67
	Check	----	100	100	100

[1] Smaller seedlings were present because of reseeding. Any reduction in yields was the result of the effect of the solvent on these small seedlings.

[2] Stand of grain sorghum reduced following 1st treatment.

The first treatments of crops at Meridian, Idaho, in 1948 included a single flood-irrigation of spring wheat during the late-boot stage. A 30-minute introduction of aromatic solvent at a concentration of 600 p. p. m. (8.1 gallons per c. f. s.) or 1,200 p. p. m. (16.2 gallons per c. f. s.) in the irrigation water caused no visible or measurable damage to this crop. However, there was a 22 percent reduction in yield on plots which received a high concentration of 2,200 p. p. m. (29.7 gallons per c. f. s.). In the same experiment, a single furrow-irrigation for 60 minutes with water containing concentrations of solvent as high as 900 p. p. m. (24.3 gallons per c. f. s.) caused no injury to potatoes in the full-bloom stage. Concentrations as high as 1,250 p. p. m. (33.75 gallons per c. f. s.) caused no damage to sweet corn in the tasseling stage.

In 1949, single 30-minute applications of aromatic solvents at rates of 400 p. p. m. (5.4 gallons per c. f. s.), 800 p. p. m. (10.8 gallons per c. f. s.), and 1,200 p. p. m. in irrigation water were made to sweet corn (silking), potatoes (early-bloom), sugar beets (2-inch diameter), and Red Mexican beans (early-bloom) by the furrow-irrigation method. Crop yields from treated plots were nearly equal to or greater than yields from untreated plots. Slightly lower yield of beans from plots treated with the lightest rate apparently was not caused by the solvent in irrigation water.

A test similar to that in 1949 was conducted in 1950 with a higher range in the concentrations of aromatic solvents applied. Concentrations of 800 p. p. m. and 1,200 p. p. m. for 30 minutes and 2,400 p. p. m. for 10 minutes (10.8 gallons per c. f. s.) caused no apparent injury to sweet corn. However, the yield of sweet corn was 12 percent less on plots treated with 1,600 p. p. m. for 30 minutes (21.6 gallons per c. f. s.) than on untreated check plots. The same concentrations apparently caused no significant damage to potatoes and Red Mexican beans. Stands of crops (especially sugar beats) and plot conditions showed considerable variation. Consequently, reductions in this experiment of as much as 36 percent in yields of beets on treated plots could not be considered highly significant.

Furrow-irrigated sugar beets, Red Mexican beans, and carrots, as well as flood-irrigated oats, were given single 30-minute applications of aromatic solvents at concentrations of 800, 1,200, 1,600, and 2,400 p. p. m. (32.4 gallons per c. f. s.) during 1951. Stands of sugar beets were more uniform in this experiment. No significant damage resulted from even the highest rate of application. Again, variations in yields of Red Mexican beans were not attributed to the solvent applications, especially since no reduction in yield occurred from the most severe treatment. Oats were not affected by any of the treatments. Yield of carrots was not reduced by applications of 800 p. p. m. of solvent in water for 30 minutes, and the significance of the somewhat reduced yields recorded for the other treatments was questionable.

Crops in these tests at Meridian, Idaho, were not significantly damaged by concentrations in irrigation water considerably higher than those currently recommended for submersed aquatic weed control.

At Phoenix, Ariz., in 1949, single 40-minute flood-irrigations with water containing 400 p. p. m. (7.2 gallons per c. f. s.) and 800 p. p. m. (14.4 gallons per c. f. s.) of aromatic solvent caused the submerged foliage on seedling alfalfa (approximately 3 inches tall) to become yellow and dry within a few days. Some small seedlings which were submerged completely appeared to be killed. In most instances, however, new shoots developed eventually from the root crowns, and the plants continued normal growth. No significant reduction in stands and no reduction in yields occurred as a result of the treatments. These treatments were repeated later in the season on more mature stands of alfalfa with no more damage than some burning of the lower leaves which actually were submerged in the treated water.

The same treatments were applied to grain sorghum at 4 different stages of development. Applications which were made during the seedling stage (average 3 inches tall) caused no injury to a great majority of the plants. However, a few small plants, which were submerged completely in the treated water, eventually died. This reduction in stand resulted in some reduction in yields. Although slight reductions in yield occurred, sorghum treated at the 14-inch and the booting stages of development showed no visible abnormalities. Applications made during the flowering period had no adverse effect on yield.

The results of treatments on cotton in this experiment were obscured by accidental injury from 2,4-dichlorophenoxyacetic acid (2,4-D). However, the single 40-minute flood-irrigations with water containing 400 p. p. m. and 800 p. p. m. of aromatic solvent were observed to kill a number of small seedlings which were completely or almost submerged in the treated water. Applications on more mature cotton plants were not detrimental.

Another experiment was conducted in 1950 on second-year alfalfa, grain sorghum, and cotton with the addition of a 40-minute application of irrigation water containing aromatic solvent at a concentration of 1,600 p. p. m. (28.8 gallons per c. f. s.). When the first applications of treated water were made on 2-year-old alfalfa, the accumulated winter growth had been removed and the new growth was 3 to 4 inches tall. All foliage which was suspended in treated water was yellowed and drying out the next day after the treatments. Some inhibition of growth was noted on all treated plots for several days thereafter, especially on those treated with a concentration of 1,600 p. p. m. This inhibition was only temporary and was no longer evident after 2 weeks. No reduction in hay yields resulted.

Similar treatments made later in the season caused some burning of lower leaves and temporary retardation of growth but caused no permanent injury or decrease in the quantity of hay produced.

Grain sorghum was planted on June 19 for the tolerance tests. Because of lack of irrigation water, the crop showed the effects of drought, and approximately 10 percent of the seedlings died. To provide uniform cover, bare areas were replanted.

The first series of solvent applications at 400, 800, and 1,600 p. p. m. for 40-minute periods were made on July 14, at which time the original planting was 6 to 8 inches tall and the replanted sorghum was still in the seedling stage. Many of these seedlings were completely sub-

merged by the flood-irrigation treatment, and a large percentage was killed. There was no evidence of damage to the original planting. Concentrations of 800 p. p. m. and 1,600 p. p. m. damaged a sufficient number of the seedling plants to reduce the yields 9 and 14 percent, respectively, as compared with the untreated checks. These results are in accord with those obtained in 1949.

The same concentrations were applied to a second series of plots on July 28, at which time the sorghum plants ranged from 6 to 14 inches high. There was no evidence of injury as a result of these treatments.

The treatments were repeated on a third series of plots on August 10 when the sorghum plants were 24 to 30 inches tall and in the boot stage. No damage resulted from these applications.

As an exploratory test, cotton seed was planted on April 3. On May 18, at which time the plants had attained a height of 6 to 8 inches, aromatic solvent was applied at concentrations of 400, 800, and 1,600 p. p. m. for 40 minutes on duplicated plots. Although some of the lower leaves were burned and eventually dropped off, none of the young plants were killed by the treatments. Subsequent growth appeared normal. However, yields of lint were somewhat lower (5 to 19 percent) on most treated plots than on untreated check plots.

A second series of applications was made on June 12, at which time the plants were in the early-bloom stage and averaged 18 inches in height. Lint yields were slightly lower on plots treated with 800 p. p. m. and 1,600 p. p. m. of solvent than on untreated plots.

A final series of plots was treated on August 3 when plants had reached an average height of 36 inches and many bolls had opened. Again, yields tended to be reduced somewhat by the solvent treatments. The tendency for solvent to reduce the yields of lint in this test led to a more precise experiment on cotton in 1951.

In 1951, as in the previous experiments, aromatic solvents were applied at concentrations of 400, 800, and 1,600 p. p. m. for 40-minute periods to grain sorghum and cotton. In flood-irrigating the grain-sorghum plots, solvent was added to the water in 3 (the first, third, and fifth) of the 6 irrigations necessary to mature the crop. Marked injury was evident on plots treated with 1,600 p. p. m. during the late seedling stage (the first irrigation). Many of the young plants collapsed during the treatment and ultimately died. A 37-percent reduction in stand was recorded. At the same time, applications of 400 and 800 p. p. m. were not injurious. The additional treatments during the third and fifth irrigations caused no further injury regardless of the concentration. Concentrations of 400 and 800 p. p. m. caused no significant reductions in the final yields of grain sorghum, but plots treated with 1,600 p. p. m. yielded 33 percent less than the check. This reduction was significant at the 1-percent level of probability.

The first series of cotton plots received single 40-minute flood irrigations with water containing 400, 800, and 1,600 p. p. m. of solvent on June 10 when the plants were 10 to 12 inches tall. The treatments were repeated on a second series of plots on July 18, at which time the plants varied from 24 to 30 inches in height. Slight contact injury, which resembled girdling, was observed on the portion of the stems submerged

in the treated water. This injury disappeared as the plants developed. Some of the lower leaves on the plants became yellow and withered immediately after the treatments. Fumes of the evaporating solvent may have caused these effects. More leaf damage occured on plots treated with 1,600 p. p. m. of solvent than on those treated with lower concentrations. Although yields of cotton lint were somewhat lower on plots treated with aromatic solvents, especially at a concentration of 1,600 p. p. m., none of the yield reductions were satistically significant.

These results indicate that severe or permanent injury to alfalfa, grain sorghum, or cotton is not likely to occur from flood irrigation with aromatic solvents at concentrations currently recommended for submersed aquatic weed control, especially if such crops have advanced beyond the seedling stage. Flood irrigation with solvent effluent should probably be avoided when these crops are in the young seedling stage, especially if such seedlings would be submerged in the treated water.

Toxicity to Soil Bacteria

In connection with the crop-tolerance tests, Jones [6] analyzed soil samples taken from solvent-treated plots at Phoenix, Ariz., and Meridian, Idaho, to determine the possible toxicity of effluent to beneficial soil bacteria. The analyses showed that the activity of ammonifying and nitrifying bacteria in the soil was not affected by aromatic solvents, even at concentrations as high as 2,400 p. p. m. which were introduced over 30-minute periods. Apparently there is little danger of destroying beneficial soil bacteria through the use of aromatic solvents at rates which presently are recommended for aquatic weed control.

Toxicity to Farm Animals

Consumption of treated water in the channels by livestock during the course of these investigations was never observed, although such water frequently was readily available to various types of farm animals. On several occasions, some farm animals actually tasted the treated water and then refused to drink it. No reports of ill effects to livestock from the use of aromatic solvents in irrigation channels have been received.

Tests were conducted by Shupe and Timmons [7] on the palatability and toxicity to guinea pigs of aromatic solvents at concentrations of 400 and 800 p. p. m. Two important points were apparent from the results: (A) the guinea pigs consumed considerably less treated water than untreated, and they almost refused to drink the heavier concentration until the third day of the test when the stress of sustained thirst apparently forced greater consumption; (B) after 3 days of confinement on treated water, with considerable quantities being consumed on the third day, none of the 32 animals showed ill effects.

Insofar as guinea pigs are comparable to farm livestock, the results of these tests seem to indicate that there is little or no hazard to live-

---

[6] Unpublished data from experiments conducted by L. W. Jones, Bact. Dept., Utah Agr. Expt. Sta.

[7] Unpublished data from experiments conducted by J. L. Shupe, Vet. Sci. Dept., Utah Agr. Expt. Sta., and F. L. Timmons, Field Crops Res. Branch, Agr. Res. Serv., U. S. Dept. Agr.

stock from drinking aromatic solvent treated water in irrigation channels. Whereas the guinea pigs were confined on treated water for 3 days, livestock rarely have access to treated water in channels for more than 2 or 3 hours at a time and usually only once or twice in a season. Moreover, livestock are under far less pressure to consume the distasteful treated water than were the guinea pigs in these experiments.

Toxicity to Fish and Other Aquatic Animal Life

Fish, crayfish, snails, and many types of bugs or insects, including mosquito larvae, were usually killed when they came in contact with treated water. The destruction of game fish was an undesirable aspect. However, the actual number of desirable fish that were killed in a treated irrigation ditch appeared to be insignificant when compared with the importance of the removal of undesirable plant and animal life.

COST OF MATERIALS AND APPLICATION

The cost of commercial aromatic solvent materials was extremely variable from locality to locality as well as from region to region, depending on availability, shipping charges, competition, and other factors. The price of ready-mixed materials containing emulsifiers ranged from $0.45 to $1.10 per gallon. When purchased separately, prices ranged from $0.18 to $0.85 per gallon for solvents and $0.94 to $7.80 per gallon for emulsifiers. The price of material was not necessarily a criterion of its effectiveness.

As an example of cost relationships on a practical scale, several irrigation projects treated small laterals at overall costs ranging from $10 to $16 per mile as compared with $80 to $200 per mile for the hand-cleaning methods used previously. Purely from a monetary standpoint, as the capacity of the channels and price of solvent materials increased, the cost of treatments approached that of mechanical control methods. Some irrigation companies and districts found that, under existing prices, wages, and equipment costs, aromatic solvents gave more economical control of submersed aquatic weeds than did other methods in channels with capacities of less than 50 to 70 c. f. s., while mechanical methods usually gave more economical control in larger channels. However, some irrigation districts found it practical to use aromatic solvents in larger canals with flows up to 150 c. f. s., especially in emergencies where immediate control was necessary to prevent overflows, breaks in canal banks, and other damage (fig. 15).

PRECAUTIONS

Since aromatic solvents are highly inflammable, the same precautions were used in handling these materials as are used in handling gasoline and similar products. Inhalation of solvent fumes, especially fumes from solvents of coal-tar origin, was avoided, and solvents were not allowed to come into contact with the skin for prolonged periods. No injuries to personnel or losses of property occurred during the experimental trials, and few have been reported from the extensive use of solvents in recent years.

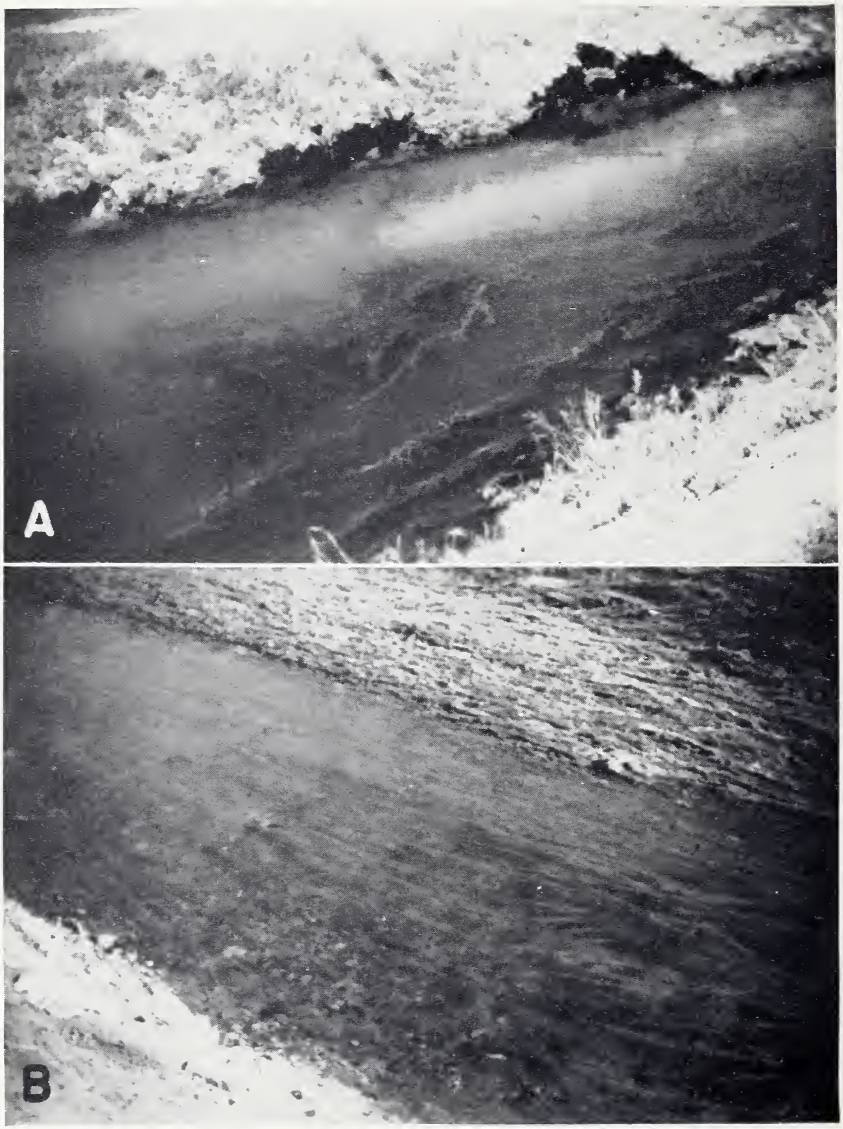

Figure 15.—*A*, In July, pondweeds 10 to 12 feet long in this canal raised the water level which caused severe erosion of the banks, seepage, and a near break. *B*, An emergency application of aromatic solvent in the same canal (150 c. f. s. waterflow) lowered the water level from 18 to 24 inches within 24 hours, and little pondweed growth was present when the water was drained in October.

SUMMARY AND CONCLUSIONS

In studies during 1947–52, involving 153 field tests at 4 stations in Washington, Idaho, Arizona, and Utah, aromatic solvents meeting certain established specifications gave satisfactory control of most kinds of submersed aquatic weeds in irrigation channels. Aromatic solvents of coal tar and of petroleum origin that met the specifications gave about equal results.

Emulsifiers of the petroleum-sulfonate type at 5 percent by volume of aromatic solvent gave satisfactory performance under most conditions, but nonionic emulsifiers at 2 percent by volume gave better results under a wider range of conditions.

A wide range in types of spraying equipment was found satisfactory for applying aromatic solvents in irrigation channels. Solvent-resistant hoses, gaskets, washers, and greases were found essential. Results tended to be better with equipment which provided for higher pressures of 100–400 p. s. i. or for mixing the solvent and emulsifier with water under pressure, giving quicker and more thorough dispersion of the emulsion in the channel. Accurate calibration of delivery rate of the equipment and accurate measurement of the rate of waterflow in the channels was necessary for predictable and satisfactory results.

Rates of 5.4 to 5.9 gallons per c. f. s. of flow in the channel gave control of waterweed (*Anacharis canadensis* (Michx.) Planchon), horned pondweed (*Zannichellia palustris* L.), and leafy pondweed (*Potamogeton foliosus* Raf.) for periods up to 5 or 6 weeks, ¾ to 1½ miles down the channel below point of application. A rate of 8.1 gallons per c. f. s. gave effective control of these species for periods up to 8 weeks and also controlled the more resistant sago pondweed (*Potamogeton pectinatus* L.). A quantity of 10 gallons of solvent per c. f. s. was found necessary for control of Richardson pondweed (*P. richardsonii* (Benn.) Rydb.), gigantic sago pondweed (*P. pectinatus* var. *interruptus* (Kit.) Aschers.), American pondweed (*P. nodosus* Poiret), and water stargrass (*Heteranthera dubia* (Jacq.) Macm.). This higher rate gave effective control for distances up to 5 miles without "booster" applications.

It was found that 30 minutes was the optimum time for introducing aromatic solvents into the channel. Applying the same amount of solvent during a 60-minute period gave equally good results, while a 15-minute introduction of the same amount of solvent appeared to be effective for a distance of no more than ¾ mile. Applications of high concentrations of 1,600 p. p. m. and 2,400 p. p. m. during shorter periods usually gave unsatisfactory control for the first ¼ to ½ mile below the point of introduction but frequently gave excellent results ¾ to 1 mile below.

Many factors were found to influence results with aromatic solvents. Natural turbulence or artificial agitation of the water at the point of introduction gave quicker and more thorough dispersion of the solvent and better control of weeds.

Optimum results occurred at water velocities of 0.75 to 1.25 feet per second (f. p. s.). Lower velocities resulted in effective control for shorter distances, while higher velocities reduced effectiveness of the treatments.

Results tended to be better at water temperatures of 70° F. or above, although good results frequently were obtained at lower temperatures.

High silt content and high salt content both reduced the effectiveness of the treatments.

Best results were obtained with solvent treatments which were applied when weed growth was beginning to interfere noticeably with the waterflow but before the plants had reached the water surface. Unsatisfactory control often occurred where dense masses of relatively mature aquatic growth were present.

Effective treatments with aromatic solvents caused submersed aquatic weeds to settle to the bottom of the channels in 24 to 48 hours and to disintegrate and slough off within 2 or 3 weeks.

Greenhouse tests at 1 station and field tests at 2 stations over periods of 1 to 3 years showed that irrigation water containing aromatic solvents at concentrations and rates found necessary to control the most resistant submersed aquatic weeds caused no economically important injury to alfalfa, Red Mexican beans, carrots, cotton, grain sorghum, Ladino white clover, lettuce, lima beans, oats, orchard grass, potatoes, sugar beets, or sweet corn. To obtain significant injury to the crops tested, it was necessary to apply 2 to 3 times the rates found necessary for aquatic weed control. Laboratory tests indicated no damage to soil bacteria from the experimental application to crops.

Aromatic solvent treated water was found to be extremely unpalatable to guinea pigs, but it caused no ill effects even when consumed in normal quantities. No cases of injury to farm livestock from drinking solvent-treated water from canals were discovered. On the other hand, the solvent treatments in channels were observed to be deadly to fish, crayfish, snails, mosquito larvae, and other aquatic animal life.

Under existing cost relationships, aromatic solvents gave more economical control of submersed aquatic weeds in smaller channels up to 50–70 c. f. s. in capacity as compared with costs reported for other methods. In larger canals, mechanical methods were usually less costly.

The precautions recommended for handling gasoline were used in handling the highly volatile and inflammable aromatic solvents, to prevent injury to personnel and damage to property.

LITERATURE CITED

(1) American Society for Testing Materials.
1953. standard method of test for distillation of gasoline, naphtha, kerosene, and similar petroleum products. astm designation: d 86–53. ASTM Standards 1952 (pt. 4) as revised, Suppl. 1953: 35–41, illus.

(2) ———
1953. calculation for olefins and aromatics in gasoline. astm designation: d 875–53 t. ASTM Standards 1952 (pt. 5) as revised, Suppl. 1953: 115–116.

(3) Arle, H. F.
[1950.] the effect of aromatic solvents and other aquatic herbicides on crop plants and animals. West. Weed Conf. Proc. 12: 58–60. [Processed.]

(4) Balcom, R. B.
1949. what price weeds? U. S. Bur. Reclam., Reclam. Era 35: 171–172, 176, illus.
(5) Boyer, B. B.
1946. aquatic weed control manual. The Cloroben Corp., Jersey City, N. J. 23 pp., illus.
(6) Bruns, V. F.
[1950.] submersed aquatic weed control in irrigation channels. West. Weed Conf. Proc. 12: 55–58. [Processed.]
(7) ——— and Farmer, W. H.
1950. aromatic solvents for waterweeds. U. S. Bur. Reclam., Reclam. Era 36: 79–80, 82, 96–97, 104, illus.
(8) Crafts, A. S.
1949. control of aquatic and ditchbank weeds. Calif. Agr. Col. Ext. Cir. 158, 16 pp., illus.
(9) Hodgson, J. M.
1952. handbook of weed control calculations U. S. Bur. Reclam. Era 36: 81, illus.
(10) ———
1952. aromatic solvents control water weeds in irrigation laterals. Idaho Agr. Col. Ext. Cir. 123, 5 pp., illus.
(11) Maletic, J. T.
1952. handbook of weed control calculations. U. S. Bur. Reclam. Tech. Rpt. 128 pp., illus. Denver, Colo. (Revised.) [Processed.]
(12) Moran, W. T., and Shaw, J. M.
1948. a new killer for water weeds. U. S. Bur. Reclam., Reclam. Era 34: 81–83, 93, illus.
(13) Shaw, J. M., and Timmons, F. L.
1949. controlling submerged water weeds on irrigation systems with aromatic solvents. U. S. Bur. Reclam., Res. and Geol. Div. Lab. Rpt. CH–97, 10 pp. Denver, Colo. [Processed.] (Joint Rpt. of U. S. Bur. Reclam. and U. S. Bur. Plant Indus., Soils, and Agr. Engin.)
(14) United States Bureau of Reclamation.
1949. control of weeds on irrigation systems. 140 pp., illus. Washington.

U. S. GOVERNMENT PRINTING OFFICE: 1955